EUSTASY AND THE YARRA DELTA, VICTORIA, AUSTRALIA

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Abstract

Radiocarbon dating and oxygen isotope palaeotemperature measurements have provided considerable support for the hypothesis of glacial control of Quaternary sea level changes. On the world temperature graph for the past 100,000 years, the local radiocarbon datings have been plotted. The inferences from this graph are considered in relation to geological observations on the Yarra Delta.

Two warmer periods of higher sea level (the Riss/Würm 25 ft and the postglacial 10 ft) are separated by a long period of lower temperatures and lower sea level when considerable erosion of the delta took place. The postglacial rise in sea-level has been dated by C14.

The possibility that tectonic movement has effected these emergences is examined. No evidence is found of late Quarternary uplift in this sunkland environment.

Introduction

As deposition on the floors of deep oceans is so slow, relatively thin deposits represent great periods of time. Cores from such deposits can span the whole of Quaternary time. Pelagic foraminifera (that once lived at the surface of the ocean) taken at intervals in such cores have been analysed for their oxygen isotope palaeotemperatures, so that graphs have been constructed of the changing ocean surface temperatures of the past (*Emiliani* 1956, 1957, 1958 a, b). Palaeoecologic analyses (Ericson and Wollin 1956) and sedimentational analyses (Broecker, Turekian and Heezen 1958) have given comparable results.

By means of radiocarbon analyses the palaeotemperature curve has been calibrated for time within the range of that method. Thus palaeoclimatic changes have been dated precisely over the past 45,000 years, and with some reliability by extrapolation to 100,000 years. Such a curve is given in Fig. 1, taken from Emiliani, but with the temperature scale adjusted to the local range (i.e. the curve begins on the local mean temperature). On this curve, radiocarbon dates of local sites have been inserted.

Radiocarbon and Glacio-eustasy

Radiocarbon dating has shown that late Quaternary climatic changes have been synchronous in the northern and southern hemispheres. They have also shown that low sea levels accompanied the low temperatures. Moreover, evidence is accumulating for similar low levels in many parts of the world at the same time (e.g. Godwin, Suggate and Willis 1958). Radiocarbon and oxygen isotope palaeotemperature measurements (Emiliani, op. cit.) have thus greatly strengthened the glacio-eustatic or glacial control hypothesis, i.e. that the Quaternary low sea levels were due chiefly to colder temperatures resulting in accumulation of ice caps on the poles and a contraction of oceanic waters, while higher sea levels were due to warmer temperatures resulting in the melting of polar ice and the expansion of oceanic waters.

If the glacial control hypothesis be correct (and the available evidence now strongly supports it), then the palaeotemperature graph in Fig. 1 provides an indication also of the changes of sea level. From this graph the following inferences may be made:

1. A mid-Holocene warmer period occurred approximately 4,000-6,000 years ago (the Postglacial Thermal Maximum). Local evidence of this, and a radiocarbon dating, have been obtained (Gill 1955a).
2. The Riss/Würm Interglacial (about 100,000 years ago) was the only other time in the period covered when the climate was warmer than the present (see Fig. 1). This is the time of the 25 ft sea (= Sangamon), and far beyond the present range of radiocarbon. Thus emerged shell beds of this age at Port Fairy have proved to be beyond the range of C_{14} (Gill 1953, 1955b); they are more lithified than the postglacial emerged beds.
3. The ocean level has been considerably lower than at present for most of the period of nearly 100,000 years between these two higher levels. This would mean a prolonged period of erosion, and would account for the deep and wide valleys with their thalwegs extending below present sea level. Many of these valleys are considerably infilled with Flandrian sediments. This prolonged period of low sea level would also have considerable significance for the distribution of plants and animals, e.g. between the Australian mainland and Tasmania.
4. A colder climate characterized this long period, and must have been another factor in the distribution of plants and animals. *Homo sapiens* emerged in the earlier part of this period, and so has spent most of his time in a colder climate. *Homo sapiens* is a glacial period species but recently accommodated to higher temperatures. The oldest C_{14} date for man in Australia is *c.* 18,000 years for charcoal from a hearth low in the Keilor Terrace (6 ft 9 in. below the diastem) at the Keilor Cranium site (Gill 1954). This date falls in the time of lowest temperatures, which on the glacial control hypothesis would also be the time of lowest sea-level. It may be that the entry of man to Australia may be connected with this time of lowest sea-level, when New Guinea would be linked with the mainland, and the sea crossing from the west was much shorter. Ancient hominids are known from China and Java (Vallois and Movius 1953), and *Homo sapiens* is known from many sites near Australia. Radiocarbon dates for a cave site in Borneo of *c.* 32,600 and *c.* 39,600 years ago are known.
5. The graph suggests two glaciations in the period concerned rather than the three divisions of Würm classic in Europe. Emiliani (1958) so interprets his graph. The Interglacial between these two glacials did not attain temperatures as high as the present, and so on the glacial control hypothesis, a sea level as high as now is not to be expected. Sea-levels higher than now which have been referred to Würm Interglacials (Gill 1953, Fairbridge and Teichert 1953) should probably be otherwise dated.

The Yarra Delta and Eustasy

The foregoing concepts (derived from the palaeotemperature graph calibrated by C_{14}) are now applied to the sediments of the Yarra Delta, and of the Maribyrnong R. terraces with which they interdigitate. Three river terraces have been distinguished so far (Gill 1955c) viz:

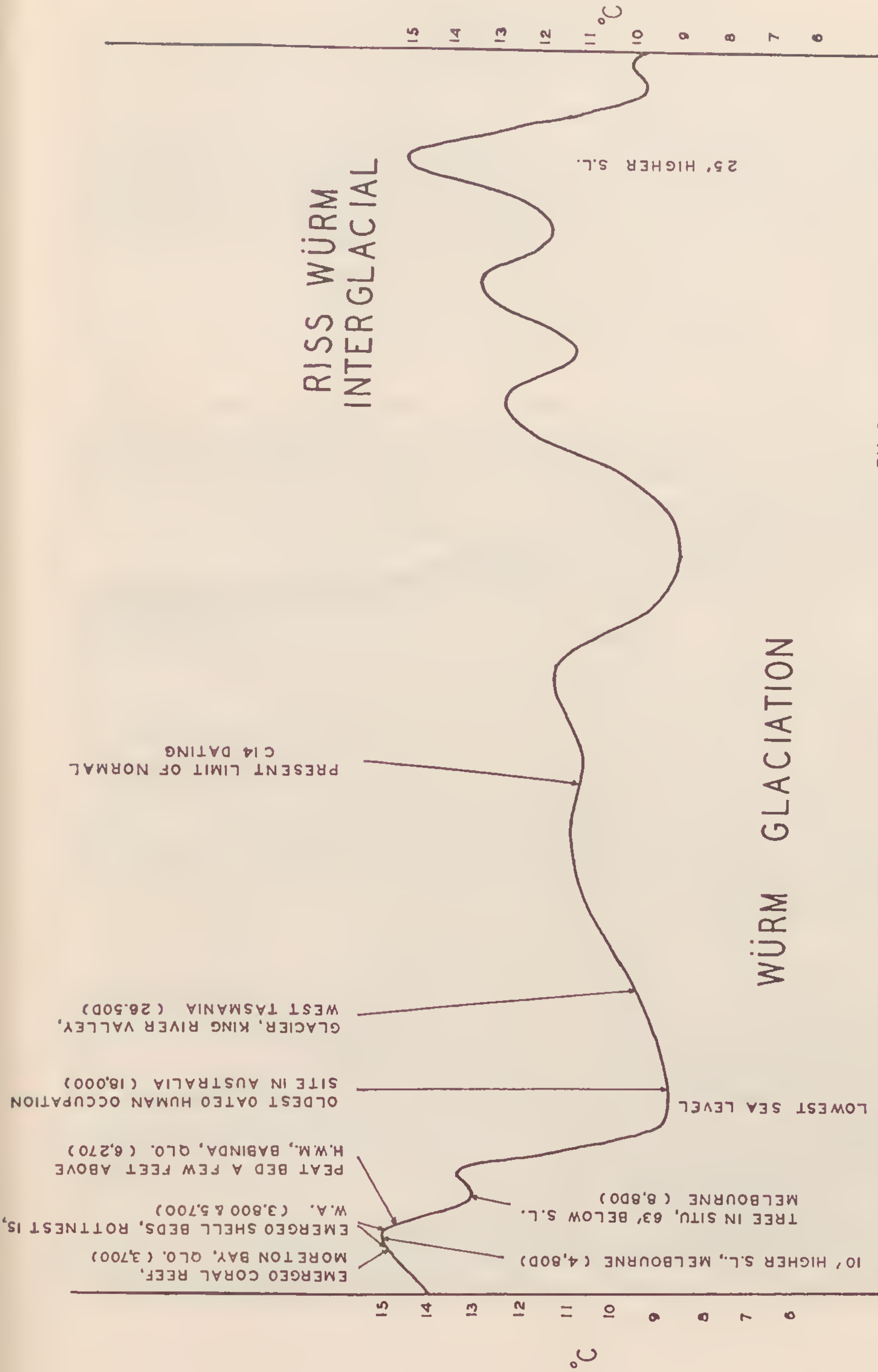

FIG. 1—Palaeotemperature curve of Emiliani adjusted to local conditions by commencing the curve on the local mean temperature. It is indicated where relevant Australian events dated by radiocarbon fit into this curve.

Oldest	Arundel Terrace
	Keilor Terrace
Youngest	Maribyrnong Terrace.

The Maribyrnong Terrace is covered (or mostly so) by present floods. The Keilor Terrace reaches some 12 ft above present flood levels. Charcoal from the higher part of the latter terrace has been dated at *c.* 8,500 years (Gill 1955d), from just below the diastem at *c.* 15,000 years, and from 6 ft 9 in. below the diastem at *c.* 18,000 years. The oxidised material of this terrace runs below present sea level. A red gum stump in position of growth 63 ft below low tide level has a similar C_{14} age to the upper part of the Keilor Terrace (Gill 1955b). This terrace belongs to the period immediately preceding and to part of the time of the Flandrian Transgression. There is evidence that the climate was wetter and cooler than now (Gill 1955b, Willis 1955, Duigan and Cookson 1957, Dorman and Gill 1959, p. 81).

A long period of time separates the Keilor Terrace from the Arundel Terrace. The top of the latter is higher in the valley, and its soil is a deep red earth. All carbonaceous matter has been destroyed, and any bones leached away. The only fossils found are some wombat teeth in a calcareous soil nodule. The sediments of the Arundel Terrace are much more consolidated than those of the Keilor Terrace. The sediments of the latter occupy a valley cut in the sediments of the Arundel Terrace, which in places underlie them.

When the Arundel Terrace is traced into the Yarra Delta (evidence to be published elsewhere) it is almost certainly associated with the consolidated, oxidized, eroded marine formation (Dorman and Gill 1959, Fig. 4) in the same way as the Keilor Terrace is associated with the overlying unoxidized, unconsolidated marine formation laid down during the Flandrian Transgression. The extent and nature of the underlying formation shows it was the result of a transgression like the Flandrian one. Its marine fossil content shows that it likewise was laid down in waters slightly warmer than the present. In this formation at North Melbourne some bones of the extinct marsupial *Diprotodon* have been found. The formation belongs to a warmer period a considerable time before the present, and prior to the last glaciation. On Emiliani's palaeotemperature curve (Fig. 1) this can only be Riss-Würm (Sangamon). The formation contains *Anadara trapezia* which is an Upper Pleistocene and Holocene lamellibranch.

Eustasy and Tectonics

The question now arises as to whether these emergences were effected to any significant degree by tectonic movements. This aspect has been referred to previously (Gill 1956, p. 137), but is now treated in greater detail. Thomas and Baragwanath (1950, Fig. 35) have outlined the structure of the Port Phillip Sunkland, including the Gellibrand Fault across the SW. margin of Hobson's Bay. This fault was originally described by Condon (1951) who believed it to be of Palaeozoic age, but still operative in the Tertiary. Movement on this fault and Selwyn's Fault, if appreciable in the past 100,000 years, would affect the formations of the Yarra Delta now under consideration.

1. The Gellibrand Fault is shown in Condon's section (1951, p. 4) as off-setting the bedrock between the Newport and Spotswood bores. The Newport bore (Stirling 1895, p. 60; 1899, p. 81) was revised by Hunter (1903) who made

an error of addition of 100 ft. Hunter also recorded the Spotswood bore. The corrected depth for bedrock removes the evidence for a fault in this section. The dip of the bedrock surface on the upthrow side of the Gellibrand Fault is determined from the Spotswood and Yarraville bores, but the latter was a private bore on which the information available is conflicting (Stirling 1899, p. 81; Bayly 1908, Fig. 3). In the writer's sections (Fig. 2, 3), Altona No. 1 bore is used (because it reached bedrock), clay and brown coal are included together (because they both belong to the stillwater ecology and they merge into one another), and the basalt is interpreted as having a flat base (because resting on clay in a sunkland environment).

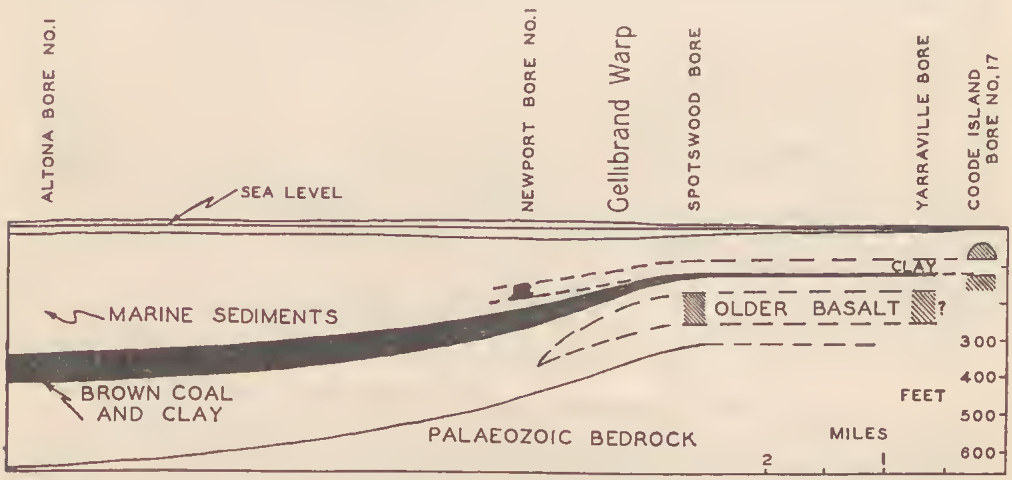

FIG. 2—Geological section from Altona to Coode Island, Melbourne, Victoria.

Owing to the uncertain character of the Yarraville bore, the section in Fig. 2 is extended to Coode Island where Bore 17 of the Melbourne Harbor Trust is included. The writer personally followed the progress of the Coode Island bores. Most were less than 100 ft in depth, but the Chairman of the M.H.T. Commissioners, Mr A. D. McKenzie, kindly had Bore 17 extended to 130 ft in the hope of reaching the Silurian bedrock, but the bore finished at that depth in Older Basalt. Lignitiferous clay found between two flows of Older Basalt in Bore 24 at 105 to 106 ft was examined by Dr Isabel Cookson, who reported that the deposit is rich in *Nothofagus* pollen, but that conifers (including *Dacrydium Mawsonii*), *Casuarina, Triorites Harrisii* and ferns are also present. The age is the same or similar to that of the brown coals of Altona and Yallourn (Oligocene).

The re-drawing of Condon's section leaves no reason for retaining at present the Gellibrand Fault, but between the Newport and Spotswood bores there is a small change in the declivity of the bedrock, so the name could be retained as the Gellibrand Warp. As both the bedrock and the brown coal are involved, the structure is a Tertiary one. The declivity of the bedrock between Spotswood and Newport is approximately 1 in 46, but 1 in 114 between Newport and Altona. Both are low declivities, but as they continue over some miles their effect is considerable. There is no evidence available yet that this structure has affected the Yarra delta in the past 100,000 years.

2. Selwyn's Fault is still active, as shown by occasional earth tremors with epicentres on or near this fault. However, the Yarra Delta is on the hinge side of this movement, and there is no evidence that the Yarra Delta has been affected over the past 100,000 years. If there were movement, it would be downwards.

3. Altona Shell Beds. These should be discussed in this connection. Pritchard (1909) rejected the usual explanation of tectonic uplift to explain the emergence of these beds, and regarded the deposits as due to 'the joint action of wind and tide' 'on a shelving shallow shore-line' building a sand bar then infilling behind it. Jutson (1931) also considered tectonic uplift doubtful, stating that 'Those deposits could easily be laid down by high tides'. Hills (1940) showed that the beds are not storm wave deposits, and interrupted them as uplifted submarine banks.

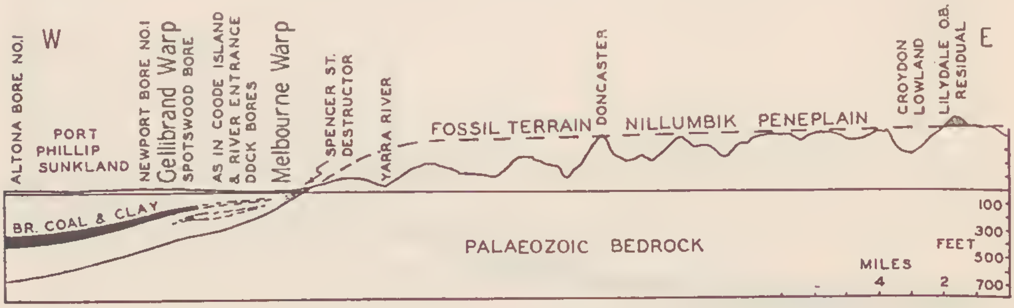

Fig. 3—Geological section from Altona to Lilydale, Victoria.

In the writer's view, two formations are present—the shell beds, and the overlying sands—and the ridges are formed by the sand, having little to do with the underlying shell beds. The latter are horizontal, poorly stratified in some places but well stratified in others. The sediments are poorly sorted, marine, shallow water, and in places current-bedded. Shells vary from complete to well-worn; occasionally the paired valves of lamellibranchs are found still together. Throughout most of the shell-bed formation, the percentage of terrigenous material is low, suggesting conditions during a transgression of the sea. Except for some marginal deposits, the formation was laid down below low water, and it constitutes a thanatocoenose. The fossils represent a mixture of facies—rock molluscs such as *Haliotis naevosa,* sand molluscs such as *Macoma deltoidalis,* weed molluscs such as *Phasianella australis,* mud molluscs such as *Anadara trapezia,* salt marsh and estuarine forms such as *Salinator fragilis,* and the calcareous-tube worm *Galeolaria* from the lower part of the intertidal space. In some beds, molluscs of one species predominate. During the excavation of a deep stormwater drain along Nellie St, S. of Lake Altona, it was noted that the shell beds are horizontal over a considerable distance.

Stratified marine beds well above high water level cannot be explained by natural reclamation as suggested by Pritchard, nor by high tides as mentioned by Jutson. The mixed facies of the fossils and the continuity of horizontal beds do not fit the theory of emerged submarine banks proposed by Hills. The shell bed formation is interpreted as a normal shallow water marine one, and is to be compared with the shell beds at Point Lonsdale and Warrnambool. Its emergence is thought to be due chiefly at least to eustatic change of sea-level; any tectonic movement would be expected to be downwards and tending to negate any emergence due to eustasy. The sand ridges are interpreted as a series of beach ridges formed during the retreat of the sea from the postglacial higher eustatic level (cf. Davies 1958). The lobate extensions on the inland sides of the ridges (mentioned by Hills) are interpreted as homologues of the blowouts on sand dunes. Similar ridges once covered Port Melbourne, which was for this reason first called Sandridge.

The Melbourne Warp

The eastern part of the City of Melbourne is built on a platform of Silurian rocks 150-200 ft above the sea. In the western part of the city, the bedrock dips down below sea level and the outcrops are of Older Basalt. The foundations for the Batman Exchange in Flinders Lane between Market St and Queen St, Melbourne, show Older Basalt resting on Silurian siltstones (observed by E. F. Halkyard). About 45 chains W. of this point, the foundations of the Lonsdale St destructor near Spencer St showed clay and sand with lenticles of gravel underlying Older Basalt. These sediments were near the shore of the lake or swamp in which the clays and lignitiferous sediments were laid down. These sediments must have been horizontal or almost so when deposited, but they are now tilted towards the S. The base of the basalt at the destructor near Spencer St is from low tide level to about 10 ft below it, while on Coode Island it is in excess of 130 ft as shown by M.H.T. Bore 17. The declivity is of the order of 32 ft per mile. The warped terrain (see Fig. 3) is the pre-Older Basalt one that forms the Nillumbik Peneplain further E., as is shown on a cross-section from Melbourne to Lilydale (Gill 1949, Fig. 3).

The increase in thickness of the Oligocene non-marine sediments to the SW., the interbedding of basalt flows in them, and the encroachment of the Miocene sea over them, suggests that the majority of the movements concerned was in those geological periods. Evidence is available of movement also during the Kosciusko Period (mainly Upper Pliocene to Pleistocene), e.g. the oxidized Pliocene sediments underlying the basalts of the Keilor and Werribee Plains are flexed far below sea level.

Maribyrnong River Valley

Keble and Macpherson (1946) claimed two warps across the Maribyrnong R. valley that are called the Keilor Warp and the Footscray Warp. That this country has been warped as a whole towards Port Phillip Bay is patent, but the degree to which these local warps are real is uncertain for the following reasons. The Keilor Warp coincides with an Older Basalt valley that runs approximately E.-W. across the path of the river. Over this basalt is Newer Basalt, so that there is a strong barrier to the river's progress. Thus there is a narrow water gap at Keilor with a very wide valley upstream from it and rapids below it. In Tertiary time the Older Basalt bar apparently caused a similar change in declivity. It is therefore possible that the change in declivity noted by the above authors is due to the basalt bar and not to a warp.

Similarly, the Footscray Warp happens to be in an area complicated by older valleys infilled with basalt. In the Standard Quarries excavation at Footscray, Newer Basalt rests almost directly on the sloping surface (presumably the wall of a valley) of the Older Basalt. On Steele Creek at Niddrie, Fowler's Quarry shows a deep Pleistocene valley infilled with flows of basalt. This same valley can be observed at Braybrook where it causes a large loop in the Maribyrnong R., and the Newer Basalt descends below sea level. Green and Irving (1958) show that the basalt in this valley has different palaeomagnetic characters from the surrounding basalts. In view of this complexity of the geology which was unrecognized at the time, the Keilor and Footscray Warps cannot yet be accepted as proved. In any case, the movement would be downwards and so tending to negate any eustatic emergence.

Conclusion

In the Port Phillip Sunkland no evidence has yet been found of measurable post-Sangamon movements affecting the Yarra Delta. If any have taken place, it may be expected that they were downwards in keeping with the sunkland pattern. The emerged marine shellbeds are therefore considered to be chiefly at least eustatic in origin; tectonic movements alone cannot explain them.

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